Researches on Growth of Plants.

By Sir Jagadis Chunder Bose, F.R.S.

I.—*The High Magnification Crescograph.*

INVESTIGATION on growth is a matter of much practical importance, since the world's food supply is intimately dependent upon vegetative growth. The movements of stems, leaves, and roots under the action of various forces, such as light, warmth, and gravity, are often due to minute variations in the rate of growth. The discovery of laws relating to the movement of growing organs thus depends on the accurate measurement of normal growth and its changes. The great difficulty of the investigation arises from the extraordinary slowness of growth, the average value of which per second may be taken as $\frac{1}{100000}$ in., or half the wave-length of sodium light. The "auxanometers" usually employed produce a magnification of about twenty times. Even here several hours must elapse before growth becomes perceptible, but during this long period the external conditions such as warmth and light would necessarily change, thus vitiating the results; moreover, autonomous variation of growth appears during lengthy periods. The elements of uncertainty can be removed only by reducing the period of experiment to a few minutes; but that would necessitate devising a method of very high magnification and the automatic record of the magnified rate of growth. I have been successful in this by my device of the High Magnification Crescograph, consisting of a system of two levers; the first magnifies a hundred times, and the second enlarges the first a hundredfold, the total magnification being 10,000 times. The various difficulties connected with the weight and friction at the bearing have been fully overcome.[1] The further difficulty in obtaining an accurate record of growth movement arising from friction of continuous contact of the writing point was removed by an oscillating device by which the smoked glass plate moves to and fro at regular intervals of time, say one second (Fig. 1). The record consists of a series of dots, the distance between successive dots representing magnified growth during a second (Fig. 2*a*).

The records may be taken on a stationary plate, first under normal, and then under changed, external conditions. The increase or diminution of space between successive dots in the two series demonstrates the stimulating or depressing nature of the changed condition (Fig. 2*d*); or the record may be taken on a plate moving at a uniform rate. In the curve thus obtained the ordinate represents growth-elongation, the abscissa the time. If a stimulating agent enhances the rate of growth, this fact is exhibited by a flexure in the curve upwards; a depressing agent, on the other hand, lessens the slope of the curve (Fig. 2*b*).

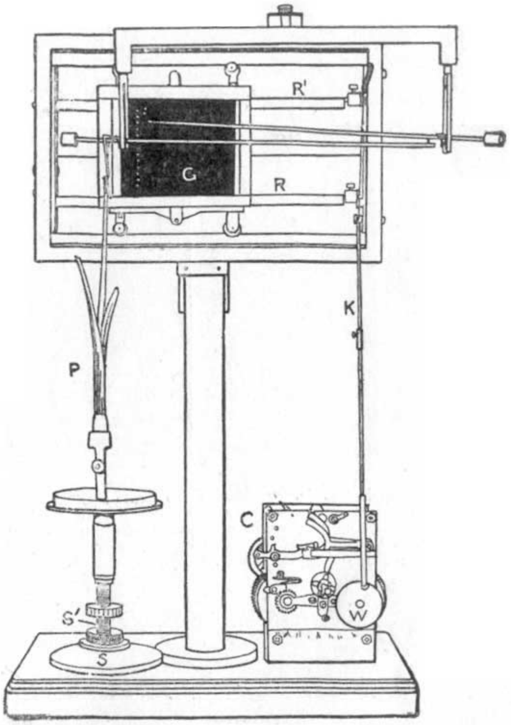

FIG. 1.—The High Magnification Crescograph. P, plant; S, S', micrometer screw for raising or lowering the plant; C, clockwork for periodic oscillation of plate; K, crank; W, rotating wheel.

Precautions against Physical Disturbance.—The effect of vibration may be neutralised by placing india-rubber sponges under the legs of a heavy table supporting the apparatus. It is preferable to screw the supporting bracket on a wall. I have, indeed, been able to secure a magnification of ten million times with my Magnetic Crescograph in public demonstrations in busy London, the indication of the instrument being quite unaffected by the street traffic. In Fig. 2*c* is given the record on a moving plate taken with the High Magnification Crescograph. A dead twig had been substituted for the growing plant, and a perfectly horizontal record demonstrated the absence not only of growth, but also of all disturbance. There is an element of physical change in experiments on variation of the rate of growth under artificially raised temperature. In order to determine its character and extent, a record was taken with the dead twig of the effect of raising the temperature of the plant-chamber through 10° C. The record shows that there was an expansion during rise of temperature, which, however, reached a limit, the record becoming once more horizontal. The obvious precaution to be taken in the study of variation of growth under change of temperature is to wait for several minutes for the attainment of steady temperature. The elongation caused by physical change abates in a short time, whereas the physiological variation in the rate of growth is persistent.

---

[1] For a fuller account see the author's "Researches on Growth and Movement in Plants by means of the High Magnification Crescograph," Proc. Roy. Soc., B, vol. cx., 1919. (The diagrams are reproduced with the kind permission of the Royal Society.) Also the following works published by Messrs. Longmans, Green, and Co.:—"Response in the Living and Non-living" (1902); "Plant Response" (1906); "Comparative Electro-physiology" (1907); "Irritability of Plants" (1913); "Life-movements in Plants," vols. i. and ii. (1918–19).

In Fig. 2*a* is given a record of growth of *Scirpus kysoor*; the growth per second magnified ten thousand times is 9·5 mm. The absolute rate of growth per second is therefore 0·00095 mm., or 0·95μ, where μ or micron is 0·001 mm.

Effect of Stimulus on Growth.—A generalisation was obtained that *all forms of stimuli, mechanical, electrical, or radiational, induce a retardation of the rate of growth;* under increasing intensity or duration of stimulus this retardation may culminate in an arrest of growth or even in actual contraction of the organ. As regards radiation, all rays of the vast æthereal spectrum (with the exception of red and yellow rays which cause photo-synthesis) are found to cause response by modifying the rate of growth of the plant. I have thus been able to obtain records of response of plants to long æther waves employed in signalling through space. (NATURE, October 30, 1919.)

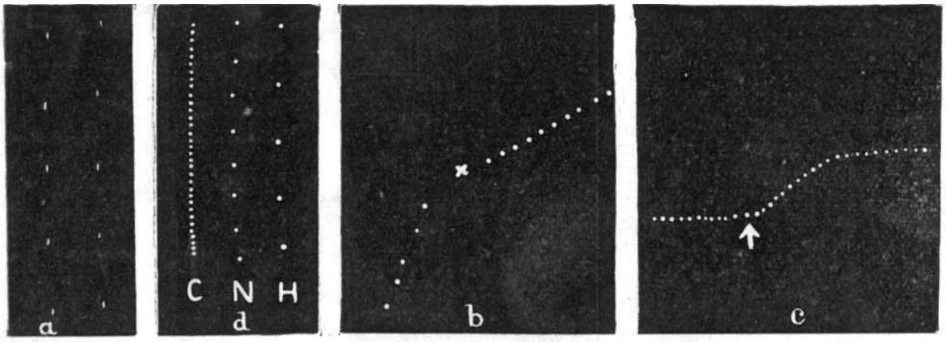

FIG. 2.—Crescographic records. *a*, Successive records of growth at intervals of 1 second; ×10,000, with a stationary plate. Effect of temperature: *d*, N, normal rate of growth; C, retarded rate under cold; H, enhanced rate under warmth; *b*, record on moving plate where diminished slope of curve denotes retarded rate under cold; *c*, horizontal record showing absence of growth in dead branch; physical expansion on application of warmth at arrow followed by horizontal record on attainment of steady temperature.

Effect of Sub-minimal Stimulus.—A very unexpected result was obtained under the action of sub-minimal stimulus, which induced an *acceleration* of growth instead of *retardation* under moderate intensity. This I find to be true of stimulation as diverse as that caused by electric shock, by light, and by chemical agents. A strikingly practical result was obtained with certain poisons which in normal doses killed the plant, but which in quantities sufficiently minute acted as an extraordinarily efficient agent for stimulating growth, the treated plants growing far more vigorously and flowering much earlier. It is only by the discovery of laws of growth that any marked advance in scientific agriculture will be rendered possible. We have been using a few stimulating agents, whereas there are thousands of the action of which we have no conception. The rule-of-thumb methods often employed in the application of a few chemical agents and of electricity have not been uniformly successful. The cause of the anomaly is found in the discovery of an important factor—namely, the dose of application—which had not hitherto been taken sufficiently into account.

The Balanced Crescograph.—The high sensitiveness already secured has been very greatly enhanced by the employment of the Null Method or the Method of Balance, where the rate of up-movement of growing tip is exactly compensated by the down-movement of the plant. A train of revolving clock-wheels, actuated by the fall of a weight, lowers the plant at the required rate. The exact adjustment is obtained by the right- or left-handed turning of a screw which regulates the governor. In this way the rate of growth becomes exactly compensated, and the recorder now dots a horizontal line instead of the former curve of ascent. The turning of the adjusting screw also moves an index against a circular scale so graduated that its reading at once gives the rate at which the plant is growing at the moment. When balanced, the recording apparatus is extremely sensitive, the effect of any change in the environment, however slight, being at once indicated by the upset of balance with the up or down movement of the indicator. I have in this way been able to detect induced variation in the rate of growth so exceedingly minute as $\frac{1}{2000000000}$ in. per second. An illustration of the delicacy of the method will be found in the record given in Fig. 3, on the effect of carbonic acid gas on growth; there is an immediate acceleration of growth (up-record), which continues for two and a half minutes; this is followed by retardation, as shown by the down curve. With diluted carbonic acid the acceleration may persist for a considerable time. As another instance of the delicacy of the method of balance, I obtained a decided response of the plant to the light so fleeting as that of a single electric spark the duration of which is of the order of $\frac{1}{100000}$ second.

The Magnetic Crescograph.—There is a limit to the magnification obtained by a compound system of levers; an additional lever increases the weight and friction. For special research and for public demonstration a still higher magnification is necessary, and this I secured by the invention of the Magnetic Crescograph, where a fine magnetised lever causes by its movement a rotation of a suspended system of astatic needle with its attached mirror. By graduated approach of the suspended needle to the lever the magnification may be continuously increased from a million to ten million times. A concrete idea of the stupendous magnification will be obtained if we imagine the slow pace of the proverbial snail magnified ten million times. The 15-in. gun of the *Queen Elizabeth* throws out a shell with a muzzle-velocity of 2360 ft. per sec., but the crescographic snail would move twenty-four times faster than the cannon shot. The magnification of ten million times was obtained with a single lever, but a double lever will enlarge it a hundredfold—that is to say, it will give a total magnification of a thousand million times. The importance of this device for research in other branches of science is sufficiently obvious. For general purposes a magnification of a million times is sufficient; with ordinary precaution the apparatus may be rendered free from mechanical disturbance, and the zero-keeping quality of the indicating spot of light is quite perfect.

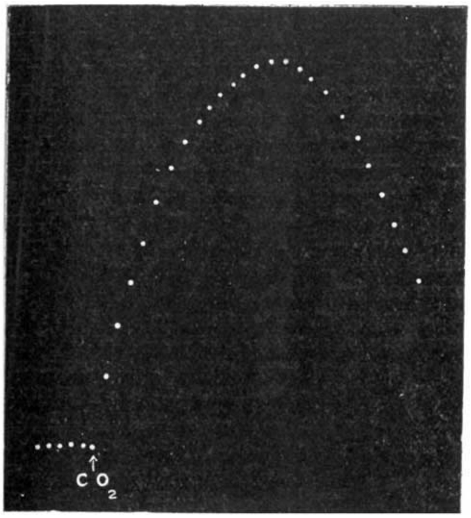

FIG. 3.—Record showing the effect of carbonic acid gas. Horizontal line at the beginning indicates balanced growth. Application of carbonic acid gas induces enhancement of growth, shown by up-curve, followed by depression, exhibited by down-curve. Successive dots at intervals of ten seconds.

The following account of an experiment in demonstration of physiological response in a growing plant will be found interesting. The normal growth of the plant was indicated by the excursion of the spot of light through 6 metres in 10 secs. On introduction of chloroform vapour to the plant-chamber there was an immediate enhancement of the rate of growth, the spot of light moving three times faster. Continued action of the vapour of chloroform caused, however, a depression and arrest of growth; finally, there was a sudden contraction, which proved to be the spasm of death. Similar effects were produced by various poisons like the solution of potassium cyanide.

After this brief account of the very sensitive methods for the detection and record of the effect of stimulus on growth, I propose in another article to describe results which will offer an explanation of the tropic movements in plants induced by various stimuli of the environment.

Isotopes and Atomic Weights.

By DR. F. W. ASTON.

IN the atomic theory put forward by John Dalton in 1801 the second postulate was: "Atoms of the same element are similar to one another and equal in weight." For more than a century this was regarded by chemists and physicists alike as an article of scientific faith. The only item among the immense quantities of knowledge acquired during that productive period which offered the faintest suggestion against its validity was the inexplicable mixture of order and disorder among the elementary atomic weights. The general state of opinion at the end of last century may be gathered from the two following quotations from Sir William Ramsay's address to the British Association at Toronto in 1897:—

> There have been almost innumerable attempts to reduce the differences between atomic weights to regularity by contriving some formula which will express the numbers which represent the atomic weights with all their irregularities. Needless to say, such attempts have in no case been successful. Apparent success is always attained at the expense of accuracy, and the numbers reproduced are not those accepted as the true atomic weights. Such attempts, in my opinion, are futile. Still, the human mind does not rest contented in merely chronicling such an irregularity; it strives to understand why such an irregularity should exist. . . . The idea . . . has been advanced by Prof. Schutzenburger, and later by Mr. Crookes, that what we term the atomic weight of an element is a mean; that when we say the atomic weight of oxygen is 16, we merely state that the average atomic weight is 16; and it is not inconceivable that a certain number of molecules have a weight somewhat higher than 32, while a certain number have a lower weight.

This idea was placed on an altogether different footing some ten years later by the work of Sir Ernest Rutherford and his colleagues on radioactive transformations. The results of these led inevitably to the conclusion that there must exist elements which have chemical properties identical for all practical purposes, but the atoms of